Final Progress Report for Research Projects Funded by Health Research Grants

Instructions: Please complete all of the items as instructed. Do not delete instructions. Do not leave any items blank; responses must be provided for all items. If your response to an item is "None", please specify "None" as your response. "Not applicable" is not an acceptable response for any of the items. There is no limit to the length of your response to any question. Responses should be single-spaced, no smaller than 12-point type. The report **must be completed using MS Word**. Submitted reports must be Word documents; they should not be converted to pdf format. Questions? Contact Health Research Program staff at 717-783-2548.

1. **Grantee Institution: Albert Einstein Healthcare Network**

2. **Reporting Period (start and end date of grant award period): 1/1/2009 – 12/31/2009**

3. **Grant Contact Person (First Name, M.I., Last Name, Degrees): Mary Klein, PhD**

4. **Grant Contact Person's Telephone Number: 215-456-7216**

5. **Grant SAP Number: 4100047622**

6. **Project Number and Title of Research Project: 04 – Development of a Haptic Virtual Environment for Upper Limb Rehabilitation**

7. **Start and End Date of Research Project: 1/1/2009 – 12/31/2009**

8. **Name of Principal Investigator for the Research Project: Steven Jax, PhD**

9. **Research Project Expenses**.

   9(A) Please provide the amount of health research grant funds spent on this project for the entire duration of the grant, including any interest earned that was spent:

   $45,232.85

   9(B) Provide the last names (include first initial if multiple individuals with the same last name are listed) of **all** persons who worked on this research project and were supported with health research funds. Include position titles (Principal Investigator, Graduate Assistant, Post-doctoral Fellow, etc.), percent of effort on project and total health research funds expended for the position. For multiple year projects, if percent of effort varied from year to year, report in the % of Effort column the effort by year 1, 2, 3, etc. of the project (x% Yr 1; z% Yr 2-3).

Last Name	Position Title	% of Effort on	Cost

		Project	
Jax	Principal Investigator	8%	$8,429
Buxbuam	Co-Investigator	8%	$7,007
Kapur	Graduate Assistant	30%	$10,194

9(C) Provide the names of **all** persons who worked on this research project, but who *were not* supported with health research funds. Include position titles (Research Assistant, Administrative Assistant, etc.) and percent of effort on project. For multiple year projects, if percent of effort varied from year to year, report in the % of Effort column the effort by year 1, 2, 3, etc. of the project (x% Yr 1; z% Yr 2-3).

Last Name	Position Title	% of Effort on Project
Kuchenbecker	Co-Investigator	8%

9(D) Provide a list of **all** scientific equipment purchased as part of this research grant, a short description of the value (benefit) derived by the institution from this equipment, and the cost of the equipment.

Type of Scientific Equipment	Value Derived	Cost
Ascension TrakSTAR	Necessary to record movements for virtual reality system	$4,858.50

10. Co-funding of Research Project during Health Research Grant Award Period. Did this research project receive funding from any other source during the project period when it was supported by the health research grant?

Yes_____ No____x_____

If yes, please indicate the source and amount of other funds:

11. Leveraging of Additional Funds

11(A) As a result of the health research funds provided for this research project, were you able to apply for and/or obtain funding from other sources to continue or expand the research?

Yes____x_____ No_____

If yes, please list the applications submitted (column A), the funding agency (National Institutes of Health—NIH, or other source in column B), the month and year when the application was submitted (column C), and the amount of funds requested (column D). If you have received a notice that the grant will be funded, please indicate the amount of funds to be awarded (column E). If the grant was not funded, insert "not funded" in column E.

Do not include funding from your own institution or from CURE (tobacco settlement funds). Do not include grants submitted prior to the start date of the grant as shown in Question 2. If you list grants submitted within 1-6 months of the start date of this grant, add a statement below the table indicating how the data/results from this project were used to secure that grant.

A. Title of research project on grant application	B. Funding agency (check those that apply)	C. Month and Year Submitted	D. Amount of funds requested:	E. Amount of funds to be awarded:
HCC: Small: Modular Tactile Feedback for Whole-Body Motion Guidance.	☐NIH ■ Other federal (specify:__NSF__ _____) ☐ Nonfederal source (specify: _____)	7/1/2009	$500,000	$500,000
Distributed Real-Time Tactile Feedback for Motion Guidance in Stroke Rehabilitation	☐NIH ☐ Other federal (specify:_____ _____) ■ Nonfederal source (specify: __L'Oreal Fellowship for Women in Science_____ ___)	12/13/10	$60,000	$60,000
	☐NIH ☐ Other federal (specify:_____ _____)		$	$

	☐ Nonfederal source (specify: _____)			

11(B) Are you planning to apply for additional funding in the future to continue or expand the research?

Yes___x_____ No_____

If yes, please describe your plans:

Once validated in younger participants (see item 12), we will apply for internal funding to allow us to pursue pilot testing in stroke survivors. Pilot data is necessary before pursuing further grant opportunities (e.g. NIH R03 or R21).

12. **Future of Research Project.** What are the future plans for this research project?

Further system refinements and behavioral testing are presently underway. If these modifications yield data indicating that the vibrotactile feedback system improves performance in younger, neurologically-intact participants, we will begin pilot testing with stroke patients to determine whether the same benefit is observed in this target population. See item 11 for further details about future grant plans related to this project.

13. **New Investigator Training and Development**. Did students participate in project supported internships or graduate or post-graduate training for at least one semester or one summer?

Yes____x_____ No_____

If yes, how many students? Please specify in the tables below:

	Undergraduate	Masters	Pre-doc	Post-doc
Male		1		
Female				
Unknown				
Total		**1**		

	Undergraduate	Masters	Pre-doc	Post-doc
Hispanic				
Non-Hispanic		1		
Unknown				
Total		**1**		

	Undergraduate	Masters	Pre-doc	Post-doc

White				
Black				
Asian		1		
Other				
Unknown				
Total		**1**		

14. Recruitment of Out-of–State Researchers. Did you bring researchers into Pennsylvania to carry out this research project?

Yes_____ No_____x_____

If yes, please list the name and degree of each researcher and his/her previous affiliation:

15. Impact on Research Capacity and Quality. Did the health research project enhance the quality and/or capacity of research at your institution?

Yes_____ No_____x_____

If yes, describe how improvements in infrastructure, the addition of new investigators, and other resources have led to more and better research.

16. Collaboration, business and community involvement.

16(A) Did the health research funds lead to collaboration with research partners outside of your institution (e.g., entire university, entire hospital system)?

Yes____x_____ No_____

If yes, please describe the collaborations:

This was the first project in what we expect will be a long collaboration between Drs. Jax and Buxbaum as Albert Einstein and Dr. Kuchenbecker and her students at the University of Pennsylvania (see items 11 and 12 for future plans).

16(B) Did the research project result in commercial development of any research products?

Yes_____ No____x_____

If yes, please describe commercial development activities that resulted from the research project:

16(C) Did the research lead to new involvement with the community?

Yes_____ No____x_____

If yes, please describe involvement with community groups that resulted from the research project:

17. Progress in Achieving Research Goals, Objectives and Aims.

List the project goals, objectives and specific aims (as contained in the grant application's strategic plan). Summarize the progress made in achieving these goals, objectives and aims for the entire grant award period. Indicate whether or not each goal/objective/aim was achieved; if something was not achieved, note the reasons why. Describe the methods used. If changes were made to the research goals/objectives/aims, methods, design or timeline since the original grant application was submitted, please describe the changes. Provide detailed results of the project. Include evidence of the data that was generated and analyzed, and provide tables, graphs, and figures of the data. List published abstracts, poster presentations and scientific meeting presentations at the end of the summary of progress; peer-reviewed publications should be listed under item 20.

This response should be a DETAILED report of the methods and findings. It is not sufficient to state that the work was completed. Insufficient information may result in an unfavorable performance review, which may jeopardize future funding. If research findings are pending publication you must still include enough detail for the expert peer reviewers to evaluate the progress during the course of the project.

Health research grants funded under the Tobacco Settlement Act will be evaluated via a performance review by an expert panel of researchers and clinicians who will assess project work using this Final Progress Report, all project Annual Reports and the project's strategic plan. After the final performance review of each project is complete, approximately 12-16 months after the end of the grant, this Final Progress Report, as well as the Final Performance Review Report containing the comments of the expert review panel, and the grantee's written response to the Final Performance Review Report, will be posted on the CURE Web site.

There is no limit to the length of your response. Responses must be single-spaced below, no smaller than 12-point type. If you cut and paste text from a publication, be sure symbols print properly, e.g., the Greek symbol for alpha (α) and beta (ß) should not print as boxes (□) and include the appropriate citation(s). DO NOT DELETE THESE INSTRUCTIONS.

Specific Aims (from original application)

Upper limb movement disorders are common and debilitating consequences of stroke. Virtual reality (VR) technology has the potential to be a useful tool for treatment. Although previous studies indicate VR rehabilitation is beneficial to stroke patients, many of these systems have had limited forms of patient feedback and have been prohibitively expensive. The overall goal of the proposed research is to develop a low cost VR system for upper limb rehabilitation that provides both visual and haptic feedback to participants. This goal will be accomplished with three specific development aims. The first aim will be to test several system components before final acquisition. The second aim will be to construct and test the system to ensure proper functioning.

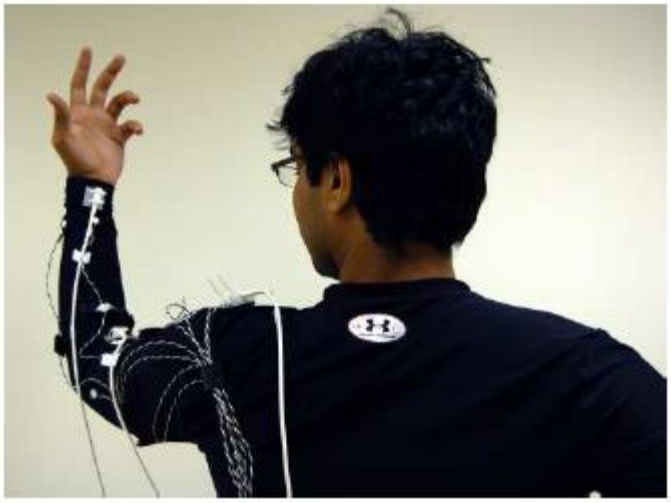
The third aim will be to prepare for future use of the system by planning experiments with stroke patients and developing proposals for additional funding.

All goals were achieved, as described separately in the sections below.

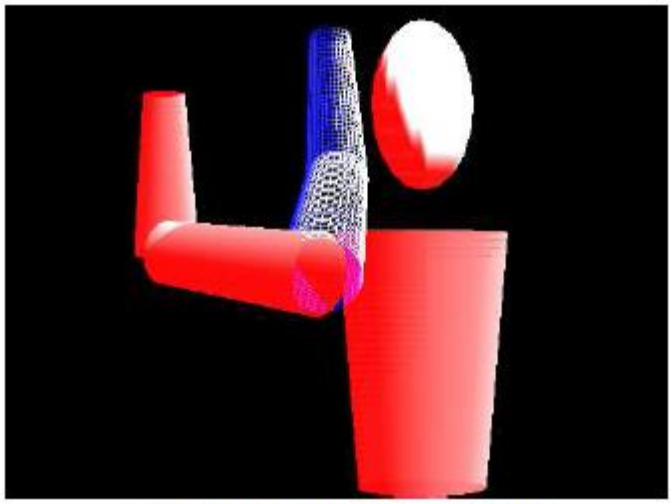
Progress towards Aim 1 (Component testing)

As part of this aim we developed five milestones, which were (1) testing of the available NaturalPoint OptiTrack system for motion recording, (2) selection of specific tactile actuators, (3) acquisition of main system components, (4) construct arm sleeve with tactors, and (5) integrate system hardware.

After extensive testing with the NaturalPoint OptiTrack motion tracking system (milestone #1), it became clear that this system was not well suited for our application. First, it required a large space to use effectively, which seemed unrealistic for future use within a clinical setting. Second, the software designed by the manufacture was not user-friendly and took a significant amount of time to learn. Because the target user of the system will be clinical staff members with limited technical skills, we believed this would be a significant hindrance in the future. For these reasons we purchased an Ascension trakSTAR motion tracking system, which uses a different approach to motion tracking that requires less space and includes a more user-friendly interface. We also tested several tactile actuators (milestone #2) for potential interference with the trakSTAR motion tracking system and found all but one (GE bass-boost headphones) interfered with the trakSTAR system. Therefore, we used this model of tactile actuator. We then acquired the remaining system hardware (milestone #3), constructed a simple arm sleeve (see panel (a) of figure below; milestone #4), and integrated all components (milestone #5). In addition to the five initial milestones, we created a basic software package that provides visual feedback to the participant (see panel (b) of figure below).



(a) User wearing the tactile interface sleeve



(b) Graphical rendering of the user's arm pose

Progress towards Aim 2 (System construction and testing)

After acquiring all of the system components, we constructed the system and tested it. Our system uses vibrotactile feedback to guide the user's arm to target poses composed of four degrees of freedom: elbow flexion/extension, shoulder inward/outward rotation, shoulder flexion/extension, and shoulder abduction/adduction. The basis of the interface is in the form of a long-sleeved Under Armour athletic shirt, with motion capture sensors and tactile actuators placed on the sleeve. A stretchable fabric was chosen to create a tight fit. This ensures that the actuators are close to the skin for good tactile sensation, and it accounts for small variations in size among users. The motion of the user's arm is measured with an electromagnetic motion tracking system. Three sensors were used in this system. Sensor one is on the forearm near the wrist, sensor two is on the upper arm (near the elbow), and sensor three is mounted on the clavicle next to the shoulder joint. Each sensor has three orthogonal coils that provide six d.o.f. (both position and orientation) information of the sensor with respect to a stationary field-

generating transmitter. Each sensor is 19 x 8 x 8 mm and has an update rate of 240 Hz. The transmitter has a maximum range of 78 centimeters. The system has a static positional accuracy of 1.4 mm (RMS) and orientation accuracy of 0.5 degrees (RMS). Velcro hooks (rough side) are attached underneath the pads that join with velcro loops (soft side) sewn onto the sleeve. Small velcro patches are also attached to the sensor cable to route it securely along the user's arm. The orientation output for each sensor is in the form of a sequence of Euler angle rotations of the sensor with respect to the transmitter reference frame.

Before use, calibration is required to account for variations in sensor mounting on the user's arm. In this step, the user is asked to mimic a calibration pose (stretching the arm straight out, perpendicular to the coronal plane) and the orientation of each sensor is recorded. During operation, our tactile feedback system is commanded with a well-defined desired arm configuration. This desired configuration may be either a static pose or a step along a recorded motion trajectory.

In designing the tactile feedback algorithm, we established a feedback policy that makes the subject want to move towards the target. There are two aspects to the design of this tactile gradient: the choice of which tactors to employ (a negative spatial cue) and the intensity with which each tactor should each be activated (an error magnitude cue). We chose to use tactile feedback derived from joint angle errors to guide the subject to target arm configurations, as we believe this may be an intuitive motion domain.

For each joint we define an angular tolerance which is used to determine whether the current pose is close enough to the goal. This angular tolerance can be adjusted for different users to make the task easier or more difficult. The first step is to determine which actuators to turn on to guide the user towards the target. We consider vibrotactile feedback provided by the tactors as a negative spatial cue which is repulsive and seeks to push the user away. The chosen tactors provide cues that make the user move in a direction that decreases the angular error. For example, a need for elbow extension is spatially signaled by tactor activation on the forearm surface that is currently facing the upper arm; this elbow angle error can be naturally corrected by moving away from the negative tactile stimulus until it disappears. The second step is to determine the intensity level for each selected tactor. The tactors may be turned on in a binary fashion, i.e., either completely on or off, or their amplitude may be a function of a system parameter, such as the desired angle or the angular error. We choose to grade the tactile signals such that their salience corresponds to the magnitude of the error. This not only reinforces the preferred direction of motion but also helps the user to dynamically determine which body part to attend to. Our tactile interface provides feedback for four degrees of freedom of the human arm: elbow flexion/extension, shoulder inward/ outward rotation, shoulder adduction/abduction and shoulder flexion/extension. Amongst these, feedback about elbow flexion/ extension and inward/outward shoulder rotational errors is provided by using four tactors located on the wrist, while feedback about shoulder flexion/extension and shoulder abduction/adduction errors is provided by using four tactors located on the upper arm near the elbow. We think of the applied stimuli as tactile joint torques that seek to reduce the angular error. It should be mentioned that the tactors are placed far from the joints being corrected to obtain the largest moment arm about the joint.

After the system was constructed and software developed for it use (which took the majority of the grant period), we informal tested the system with member of the lab on repeated occasions throughout the construction process. These tests indicated that movements of the arm within sleeve matched the visual feedback provided with the computer monitor, and that the use of negative spatial cues was helpful in guiding the arm.

Progress towards Aim 3 (Prepare for future studies)
After completing the system construction, the team presented the system as a demonstration at a national conference (World Haptics conference; Kapur et al., 2009) and then wrote up a paper which was published in the proceedings of a second national conference (IEEE Haptics Symposium Conference; Kapur et al., 2010). In addition to these disseminations, the group designed a pilot study involving neurologically-intact college students to determine whether the system is helpful in learning novel movements. This pilot study, which was completed outside the purview of the present grant, indicated the need for further system refinements and behavioral testing, which are presently underway. If these modifications yield data indicating that the vibrotactile feedback system improves performance in younger, neurologically-intact participants, we will begin pilot testing with stroke patients to determine whether the same benefit is observed in this target population.

Kapur, P., Jensen, M., Buxbaum, L. J., Jax, S. A., & Kuchenbecker, K. J. (2010). Spatially distributed tactile feedback for kinesthetic motion guidance. Proceedings of the 2010 IEEE Haptics Symposium Conference.

Kapur, P., Premakumar, S., Jax, S. A., Buxbaum, L. J., Dawson, A. M., & Kuchenbecker, K. J. (2009, March). Vibrotactile feedback system for intuitive upper-limb rehabilitation. Demonstration presented at the 3rd World Haptics conference, Salt Lake City, Utah.

18. Extent of Clinical Activities Initiated and Completed. Items 18(A) and 18(B) should be completed for all research projects. If the project was restricted to secondary analysis of clinical data or data analysis of clinical research, then responses to 18(A) and 18(B) should be "No."

18(A) Did you initiate a study that involved the testing of treatment, prevention or diagnostic procedures on human subjects?
_____Yes
___x___No

18(B) Did you complete a study that involved the testing of treatment, prevention or diagnostic procedures on human subjects?
_____Yes
__x____No

If "Yes" to either 18(A) or 18(B), items 18(C) – (F) must also be completed. (Do NOT complete 18(C-F) if 18(A) and 18(B) are both "No.")

18(C) How many hospital and health care professionals were involved in the research project?

_____Number of hospital and health care professionals involved in the research project

18(D) How many subjects were included in the study compared to targeted goals?

_____Number of subjects originally targeted to be included in the study
_____Number of subjects enrolled in the study

Note: Studies that fall dramatically short on recruitment are encouraged to provide the details of their recruitment efforts in Item 17, Progress in Achieving Research Goals, Objectives and Aims. For example, the number of eligible subjects approached, the number that refused to participate and the reasons for refusal. Without this information it is difficult to discern whether eligibility criteria were too restrictive or the study simply did not appeal to subjects.

18(E) How many subjects were enrolled in the study by gender, ethnicity and race?

Gender:
_____Males
_____Females
_____Unknown

Ethnicity:
_____Latinos or Hispanics
_____Not Latinos or Hispanics
_____Unknown

Race:
_____American Indian or Alaska Native
_____Asian
_____Blacks or African American
_____Native Hawaiian or Other Pacific Islander
_____White
_____Other, specify:_____
_____Unknown

18(F) Where was the research study conducted? (List the county where the research study was conducted. If the treatment, prevention and diagnostic tests were offered in more than one county, list all of the counties where the research study was conducted.)

19. Human Embryonic Stem Cell Research. Item 19(A) should be completed for all research projects. If the research project involved human embryonic stem cells, items 19(B) and 19(C) must also be completed.

19(A) Did this project involve, in any capacity, human embryonic stem cells?
_____Yes
___x___ No

19(B) Were these stem cell lines NIH-approved lines that were derived outside of Pennsylvania?
_____Yes
___x___ No

19(C) Please describe how this project involved human embryonic stem cells:

20. Articles Submitted to Peer-Reviewed Publications.

20(A) Identify all publications that resulted from the research performed during the funding period and that have been submitted to peer-reviewed publications. Do not list journal abstracts or presentations at professional meetings; abstract and meeting presentations should be listed at the end of item 17. **Include only those publications that acknowledge the Pennsylvania Department of Health as a funding source** (as required in the grant agreement). List the title of the journal article, the authors, the name of the peer-reviewed publication, the month and year when it was submitted, and the status of publication (submitted for publication, accepted for publication or published.). Submit an electronic copy of each publication, listed in the table, in a PDF version 5.0.5 format, 1,200 dpi. Filenames for each publication should include the number of the research project, the last name of the PI, the number of the publication and an abbreviated research project title. For example, if you submit two publications for PI Smith for the "Cognition and MRI in Older Adults" research project (Project 1), and two publications for PI Zhang for the "Lung Cancer" research project (Project 3), the filenames should be:

Project 1 – Smith – Publication 1 – Cognition and MRI
Project 1 – Smith – Publication 2 – Cognition and MRI
Project 3 – Zhang – Publication 1 – Lung Cancer
Project 3 – Zhang – Publication 2 – Lung Cancer

If the publication is not available electronically, provide 5 paper copies of the publication.

Note: The grant agreement requires that recipients acknowledge the Pennsylvania Department of Health funding in all publications. Please ensure that all publications listed acknowledge the Department of Health funding. If a publication does not acknowledge the funding from the Commonwealth, do not list the publication.

Title of Journal	Authors:	Name of Peer-	Month and	Publication

Article:		reviewed Publication:	Year Submitted:	Status (check appropriate box below):
1. Spatially Distributed Tactile Feedback for Kinesthetic Motion Guidance.	Pulkit Kapur, Mallory Jensen, Laurel J. Buxbaum, Steven A. Jax, and Katherine J. Kuchenbecker	Proceedings of the 2010 IEEE Haptics Symposium Conference	October 2009	☐Submitted ☐Accepted ■Published
2.				☐Submitted ☐Accepted ☐Published
3.				☐Submitted ☐Accepted ☐Published

20(B) Based on this project, are you planning to submit articles to peer-reviewed publications in the future?

Yes___ _____ No_____X_____

If yes, please describe your plans:

21. Changes in Outcome, Impact and Effectiveness Attributable to the Research Project. Describe the outcome, impact, and effectiveness of the research project by summarizing its impact on the incidence of disease, death from disease, stage of disease at time of diagnosis, or other relevant measures of outcome, impact or effectiveness of the research project. If there were no changes, insert "None"; do not use "Not applicable." Responses must be single-spaced below, and no smaller than 12-point type. DO NOT DELETE THESE INSTRUCTIONS. There is no limit to the length of your response.

Overall, the project achieved its goal of the design and construction of a virtual reality system which provides vibrotactile feedback to guide movements. The details of the design and construction of the system have been presented at two national conferences and includes one published paper. Later follow-up work not funded by the present grant resulted in an additional paper on our initial experiences with pilot testing the system in college students. We believe that within a year we will be able to start pilot testing the system as a therapy for stroke patients.

22. Major Discoveries, New Drugs, and New Approaches for Prevention Diagnosis and Treatment. Describe major discoveries, new drugs, and new approaches for prevention, diagnosis and treatment that are attributable to the completed research project. If there were no major discoveries, drugs or approaches, insert "None"; do not use "Not applicable."

Responses must be single-spaced below, and no smaller than 12-point type. DO NOT DELETE THESE INSTRUCTIONS. There is no limit to the length of your response.

If pilot testing in healthy controls indicate it improves performance in younger, neurologically-intact participants, we will begin pilot testing with stroke patients to determine whether the same system can be a useful therapeutic device for this large clinical population.

23. Inventions, Patents and Commercial Development Opportunities.

23(A) Were any inventions, which may be patentable or otherwise protectable under Title 35 of the United States Code, conceived or first actually reduced to practice in the performance of work under this health research grant? Yes_____ No___x_____

If "Yes" to 23(A), complete items a – g below for each invention. (Do NOT complete items a - g if 23(A) is "No.")

a. Title of Invention:

b. Name of Inventor(s):

c. Technical Description of Invention (describe nature, purpose, operation and physical, chemical, biological or electrical characteristics of the invention):

d. Was a patent filed for the invention conceived or first actually reduced to practice in the performance of work under this health research grant?
Yes_____ No____

If yes, indicate date patent was filed:

e. Was a patent issued for the invention conceived or first actually reduced to practice in the performance of work under this health research grant?
Yes_____ No____
If yes, indicate number of patent, title and date issued:
Patent number:
Title of patent:
Date issued:

f. Were any licenses granted for the patent obtained as a result of work performed under this health research grant? Yes_____ No____

If yes, how many licenses were granted?_____

g. Were any commercial development activities taken to develop the invention into a commercial product or service for manufacture or sale? Yes___ No____

If yes, describe the commercial development activities:

23(B) Based on the results of this project, are you planning to file for any licenses or patents, or undertake any commercial development opportunities in the future?

Yes_____ No_____

If yes, please describe your plans:

24. Key Investigator Qualifications. Briefly describe the education, research interests and experience and professional commitments of the Principal Investigator and all other key investigators. In place of narrative you may insert the NIH biosketch form here; however, please limit each biosketch to 1-2 pages. *For Nonformula grants only – include information for only those key investigators whose biosketches were not included in the original grant application.*

NAME Steven Jax	POSITION TITLE Institute Scientist
eRA COMMONS USER NAME (credential, e.g., agency login)	

EDUCATION/TRAINING

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	MM/YY	FIELD OF STUDY
University of Minnesota, Twin Cities	BA	1999	Psychology
Pennsylvania State University	MS	2002	Cognitive Psychology
Pennsylvania State University	PhD	2005	Cognitive Psychology
University of Pennsylvania & Moss Rehabilitation Research Institute	NIH NRSA Postdoctoral Fellowship	2005 - 2007	Cognitive Neuroscience

A. **Positions and Honors.** List in chronological order previous positions, concluding with your present position. List any honors. Include present membership on any Federal Government public advisory committee.

1999 – 2004	Teaching Assistant, Pennsylvania State University
2003 – 2004	Lecturer, Pennsylvania State University
2005 – 2007	Postdoctoral Fellow, University of Pennsylvania & Moss Rehabilitation Research Institute
2007 – present	Institute Scientist, Moss Rehabilitation Research Institute

B. P**eer-reviewed publications or manuscripts in press (in chronological order).**

*Palluel-Germain, R., ***Jax, S. A.**, & Buxbaum, L. J. (2011). Visuo-motor gain adaptation and generalization following left hemisphere stroke. *Neuroscience Letters, 498,* 222 – 226.

* = The first two authors contributed equally to this work

Jax, S. A., & Buxbaum, L. J. (2010). Response interference between functional and structural actions linked to the same familiar object. *Cognition, 115(2),* 350 - 355.

Kapur, P., Jensen, M., Buxbaum, L. J., **Jax, S. A.,** & Kuchenbecker, K. J. (2010). Spatially distributed tactile feedback for kinesthetic motion guidance. *Proceedings of the 2010 IEEE Haptics Symposium Conference, 519 – 526.*

Medina, J., **Jax, S. A.,** Brown, M. J., & Coslett, H. B. (2010). Contributions of efference copy to limb localization: Evidence from deafferentation. *Brain Research, 1355,* 104 – 111.

Vaughan, J., Barany, D., Sali, A., **Jax, S. A.,** & Rosenbaum, D. A. (2010). Extending Fitts' Law to three-dimensional obstacle-avoidance movements: Support for the posture-based motion planning model. *Experimental Brain Research, 207(1-2),* 133 – 138.

Botvinick, M., Buxbaum, L. J., Bylsma, L., & **Jax, S. A.** (2009). Toward an integrated account of object and action selection: A computational analysis and empirical findings from reaching-to-grasp and tool use. *Neuropsychologia, 47(2),* 671 - 683. PMC Journal – In Process.

Jax, S. A., Buxbaum, L. J., Lie, E., & Coslett, H. B. (2009). More than (where the target) meets the eyes: Disrupted visuomotor transformations in optic ataxia. *Neuropsychologia, 47 (1),* 230 - 238. PMC2678860.

Jax, S. A., & Coslett, H. B. (2009). Disorders of the perceptual-motor system. In Dagmar Sternad (Ed.), *Progress in Motor Control – A multidisciplinary perspective (pp. 377 - 391).* Springer.

Jax, S. A., & Rosenbaum, D. A. (2009). Hand path priming in manual obstacle avoidance: Rapid decay of dorsal stream information. *Neuropsychologia, 47,* 1573 - 1577. PMC Journal – In Process.

Medina, J., **Jax, S. A.**, & Coslett, H. B. (2009). Two-component models of reaching: Evidence from deafferentation in a Fitts' Law task. *Neuroscience Letters, 451(3),* 222 - 226.

Jax, S. A., & Rosenbaum, D. A. (2007). Hand path priming in manual obstacle avoidance: Evidence that the dorsal stream does not only control visually guided actions in real time. *Journal of Experimental Psychology: Human Perception and Performance, 33,* 425 - 441.

Jax, S. A., Rosenbaum, D. A., & Vaughan, J. (2007). Extending Fitts' Law to manual obstacle avoidance. *Experimental Brain Research, 180,* 775 - 779.

Rosenbaum, D. A., Cohen, R. G., **Jax, S. A.,** Van Der Wel, R., & Weiss, D. J. (2007). The problem of serial order in behavior: Lashley's legacy. *Human Movement Science,* 26, 525 - 554.

Van Der Wel, P. R., Fleckenstein, R., **Jax, S. A.**, & Rosenbaum, D. A. (2007). Hand path priming in manual obstacle avoidance: Evidence for abstract spatio-temporal forms in human motor control. *Journal of Experimental Psychology: Human Perception and Performance, 33,* 1117 - 1126.

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Jax, S. A., Rosenbaum, D. A., Vaughan, J., & Meulenbroek, R. G. J. (2003). Computational motor control and human factors: Modeling movements in real and possible environments. *Human Factors, 45,* 5 - 27.

NAME Laurel J. Buxbaum	POSITION TITLE Institute Scientist; Associate Research Professor, Department of Rehabilitation Medicine
eRA COMMONS USER NAME (credential, e.g., agency login) LBUXBAUMMRRI	

EDUCATION/TRAINING

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	MM/YY	FIELD OF STUDY
University of Pennsylvania, Philadelphia, PA	BA, *Cum Laude*	1982	Biological Bases of Behavior
Hahnemann University, Philadelphia, PA	PsyD	1988	Clinical Psychology
Hahnemann University, Philadelphia, PA	Internship	1987-1988	Clinical Neuropsychology
University of Pennsylvania & Moss Rehabilitation Research Institute	NRSA Postdoctoral Fellowship	1992-1994	Cognitive Neuroscience Research

A. Positions and Honors.

<u>Positions and Employment</u>

1988 – 1990 Director of Neuropsychological Services, Northwestern Institute, Philadelphia
1989 – 2000 Adjunct Assistant Professor, School of Allied Health Professionals, Hahnemann University
1990 – 1992 Neuropsychologist, MossRehab
1994 – 1996 Investigator, Moss Rehabilitation Research Institute
1994 – 1996 Project Coordinator for NIH-NINDS R01-NS-31824, "Organization and Breakdown of Routine Action Skills (Myrna F. Schwartz, P.I.)
1999 Invited Visiting Scientist, Institut des Sciences Cognitives, Lyon, France
1996 – 2000 Clinical Assistant Professor, Temple University School of Medicine
2000 – Present Associate Research Professor, Department of Rehabilitation Medicine, Jefferson Medical College of Thomas Jefferson University
1996 – Present Research Scientist, Moss Rehabilitation Research Institute; Director of Cognition and Action Laboratory
2009- Present Director of Right Hemisphere Stroke Center, MossRehab

B. Selected peer-reviewed publications (from > 55 peer-reviewed publications).

1. Buxbaum, LJ, Permaul, P. Hand-centered attentional and motor asymmetries in unilateral neglect. *Neuropsychologia*, 39, 653-664, 2001. PMID:11311296

2. Buxbaum, LJ. Ideomotor apraxia: A call to action. *Neurocase*, 7, 445-58, 2001. PMID : 11788737

3. Buxbaum, LJ, Sirigu, A, Schwartz, MF, Klatzky, R. Cognitive representations of hand posture in ideomotor apraxia. *Neuropsychologia*, 41, 1091-1113, 2003. PMID: 12667544.

4. Buxbaum, LJ, Ferraro, MK, Veramonti, T, Farnè, A, Whyte, J, Ladavas, E, Frassinetti, F, Coslett, HB. Hemispatial neglect: subtypes, neuroanatomy, and disability. *Neurology*, 62, 749-765, 2004. PMID:15007125

5. Buxbaum, LJ, Kyle, K, Menon R. On beyond mirror neurons: Internal representations subserving imitation and recognition of skilled object-related actions in humans. *Cognitive Brain Research*, 25(1), 226-239, 2005. PMID: 15996857.

6. Boronat, C., Buxbaum, LJ, Coslett, HB, Tang, K, Saffran, EM, Kimberg, DY, Detre, JA. Distinctions between function and manipulation knowledge of objects: Evidence from functional magnetic resonance imaging. *Cognitive Brain Research*, 23(2-3), 361-373, 2005. PMID: 15820643

7. Jax, S., Buxbaum, LJ, Moll, A. Deficits in movement planning and intrinsic coordinate control in ideomotor apraxia. *Journal of Cognitive Neuroscience*, 18(12), 2063-2076, 2006. PMID: 17129191.

8. Barrett, AM, Buxbaum, LJ, Coslett, HB, Heilman, KM, Hillis, AG, , Millberg, W. Cognitive rehabilitation interventions for neglect and related disorders: moving from bench to bedside in stroke patients. *Journal of Cognitive Neuroscience*, 18(7), 1223-1236, 2006. PMID:16839294

9. Buxbaum, LJ, Kyle, KM, Tang, K, Detre, JM. Neural substrates of knowledge of hand postures for object grasping and functional object use: Evidence from fMRI. *Brain Research*, 1117(1) 175-185, 2006. PMID: 16962075.

10. Barde, LHF, Buxbaum, LJ, Moll, A. Abnormal reliance on object structure in apraxics' learning of novel object-related actions. *Journal of the International Neuropsychological Society*, 13(6), 997-1008, 2007. PMID:17942018

11. Dawson, AM., Buxbaum, LJ, Rizzo, AA. The Virtual Reality Lateralized Attention Test: Sensitivity and validity of a new clinical tool for assessing hemispatial neglect. *IEEE XPlore*, Virtual Rehabilitation, Issue 25-27, 77 – 82, 2008.

12. Botvinick, MM, Buxbaum, LJ, Bylsma LM, Jax, SA. Toward an integrated account of object and action selection: A computational analysis and empirical findings from reaching-to-grasp and tool use. *Neuropsychologia*, 47(3), 671-83, 2009. PMID: 19100758.

13. Jax, S., and Buxbaum, LJ. Response interference between functional and structural actions linked to the same familiar object. *Cognition*, 115(2)*:* 350-355, 2010. PMID: 20156619

NAME Katherine Julianne Kuchenbecker	POSITION TITLE Skirkanich Assistant Professor of Innovation, University of Pennsylvania
eRA COMMONS USER NAME (credential, e.g., agency login)	

EDUCATION/TRAINING

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	MM/YY	FIELD OF STUDY
Stanford University, Stanford, California	B.S.	06/00	Mechanical Engineering
Stanford University, Stanford, California	M.S.	06/02	Mechanical Engineering
Stanford University, Stanford, California	Ph.D.	06/06	Mechanical Engineering
Johns Hopkins University, Baltimore, MD	PostDoc	08/06 - 06/07	Mechanical Engineering

A. Positions and Honors

Positions and Employement

2000-2002 Teaching Assistant, Department of Mechanical Engineering, Stanford University, Stanford, CA

2002-2006 Research Assistant, Department of Mechanical Engineering, Stanford University, Stanford, CA
Advisor: Dr. Günter Niemeyer

2006-2007 Postdoctoral Research Fellow, Department of Mechanical Engineering, Johns Hopkins University, Baltimore, MD Advisor: Dr. Allison M. Okamura

2006-present Skirkanich Assistant Professor of Innovation in Mechanical Engineering and Applied Mechanics, University of Pennsylvania, Philadelphia, PA

2010-present Bioengineering Graduate Group Member, University of Pennsylvania, Philadelphia, PA

B. Selected Peer-reviewed Publications

1. Günter Niemeyer, **Katherine J. Kuchenbecker**, Raymond Bonneau, Probal Mitra, Andrew Reid, Jonathan Fiene, and Grant Weldon. THUMP: An immersive haptic console for surgical simulation and training. In Proc. Medicine Meets Virtual Reality, pages 272–274, January 2004.
2. William R. Provancher, Mark R. Cutkosky, **Katherine J. Kuchenbecker**, and Günter Niemeyer. Contact location display for haptic perception of curvature and object motion. International Journal of Robotics Research, 24(9):691–702, September 2005.

3. **Katherine J. Kuchenbecker** and Günter Niemeyer. Induced master motion in force-reflecting teleoperation. ASME Journal of Dynamic Systems, Measurement, and Control, 128(4):800–810, December 2006.
4. **Katherine J. Kuchenbecker**, Jonathan P. Fiene, and Günter Niemeyer. Improving contact realism through event-based haptic feedback. IEEE Transactions on Visualization and Computer Graphics, 12(2):219–230, March/April 2006.
5. Allison M. Okamura, **Katherine J. Kuchenbecker**, and Mohsen Mahvash. Measurement-based modeling for haptic rendering. In Ming Lin and Miguel Otaduy, editors, Haptic Rendering: Algorithms and Applications, chapter 21, pages 443–467. A. K. Peters, May 2008.
6. Joseph M. Romano, Alla Safonova, and **Katherine J. Kuchenbecker**. Real-time graphic and haptic simulation of deformable tissue puncture. In Proc. Medicine Meets Virtual Reality, January 2009.
7. **Katherine J. Kuchenbecker**, Joseph M. Romano, and William McMahan. Haptography: Capturing and recreating the rich feel of real surfaces. Invited paper at International Symposium on Robotics Research, August 2009. To appear as a chapter in a Springer Tracts in Advanced Robotics book.
8. Quentin Lindsey, Neil Tenenholtz, David I. Lee, and **Katherine J. Kuchenbecker**. Image-enabled force feedback for robotic teleoperation of a flexible tool. In Proc. IASTED International Conference on Robotics and Applications, pages 224–233, November 2009.
9. Meng Yang, Jingwan Lu, Alla Safonova, and **Katherine J. Kuchenbecker**. GPU methods for real-time haptic interaction with 3D fluids. In Proc. IEEE International Workshop on Haptic Audio-Visual Environments and Games (HAVE), pages 24–29, November 2009.
10. William McMahan, Joseph M. Romano, Amal M. Abdul Rahuman, and **Katherine J. Kuchenbecker**. High frequency acceleration feedback significantly increases the realism of haptically rendered textured surfaces. In Proc. IEEE Haptics Symposium, pages 141–148, March 2010.
11. Pulkit Kapur, Mallory Jensen, Laurel J. Buxbaum, Steven A. Jax, and **Katherine J. Kuchenbecker**. Spatially distributed tactile feedback for kinesthetic motion guidance. In Proc. IEEE Haptics Symposium, pages 519–526, March 2010.
12. Joseph M. Romano, Takashi Yoshioka, and **Katherine J. Kuchenbecker**. Automatic filter design for synthesis of haptic textures from recorded acceleration data. In Proc. IEEE International Conference on Robotics and Automation, pages 1815–1821, May 2010.
13. Amy Blank, Allison M. Okamura, and **Katherine J. Kuchenbecker**. Identifying the role of proprioception in upper-limb prosthesis control: Studies on targeted motion. ACM Transactions on Applied Perception, 7(3):1–23, June 2010.